Innophos®

Whitepaper

Meat Substitutes: Formulating with Plant-based Proteins

Meat Substitutes with Great Taste and Texture

Demand for meat substitutes continues to grow. Consumers are choosing plant-based products to improve their health and protect the planet. To meet rising demand, manufacturers are developing new meat substitutes that mimic animal protein. Yet, they face many challenges in taste and texture. At Innophos, we offer solutions to help manufacturers overcome these challenges.

Key Messages:

- Plant-based meat substitutes have gone mainstream.
- Differences in meat myofibrillar proteins and plant-based globular proteins create formulation challenges.
- Mechanical processing is not enough to overcome the challenges of texture and taste in plant-based proteins.
- The right protein and phosphate combination ensures the best texture and taste.
- Innophos' expertise in phosphate chemistry helps manufacturers optimize plant-based products.

Innophos

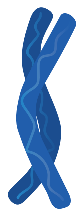
Meat Substitutes Have Gone Mainstream

Demand for meat substitutes is growing, and the market is positioned for continued expansion and innovation. The global plant-based meat market is projected to increase from $4.3 billion in 2020 to $8.3 billion in 2025, growing at a CAGR of 14.0%.[1] Demand for plant-based substitutes is growing steadily as more consumers adopt flexitarian/reduced meat diets for health reasons. In a recent survey of U.S. Consumers, nearly 65% reported eating plant-based meat substitutes during the last year and 22% said that they consumed them daily.[2]

As the consumer base for meat alternatives expands, consumer expectations are also rising for plant-based products that match the texture and flavor of meat.

The Challenge

Muscle
MYOFIBRILLAR PROTEINS



≠

Plant-Based Meat
GLOBULAR PROTEINS

WAYS TO SOLVE

1. Mechanical processing (extrusion, shearing, spinning)

\+

2. Addition of phosphate technologies to improve protein functionality

The Challenge of Formulating Plant-Based Meat Substitutes

The texture of meat comes from muscle, which is composed of individual elongated fibers joined by connective tissue. Each muscle fiber consists of numerous myofibrils which in turn, are comprised of myofilaments, long protein chains of myosin and actin. This myofilament matrix provides a physical space where water is trapped by capillary forces, H-bonds, or ion-dipole interactions. The myofibrillar proteins (MPs) have heat-induced gelling properties and fat emulsifying abilities. These properties play a critical role in producing the viscoelastic textural attributes of cooked meat when it is consumed.

Plant-based proteins, such as soy and pea, have a globular structure. This structure creates challenges when developing products with a fibrous texture. Globular proteins cannot impart the highly organized fibrous texture and water holding capacity (WHC) seen in muscle fibers due to differences in amino acid composition and sequence, protein structure and the molecular association and structural alignment.

Transforming these globular proteins into linear muscle-like proteins and increasing the WHC is a first step towards improving mouthfeel and in achieving a viable alternative to meat products.[3,4]

Mechanical processing techniques, such as extrusion, shearing, spinning, and mixing, can improve the texture of plant-based proteins. Yet, these processing techniques are not sufficient on their own to mimic the organoleptic properties of meat products.

Phosphates are key ingredients in developing appealing meat substitutes because they impact protein functionality (for example: ability to form gels, hold water, absorb fat, emulsify). These functionalities impart sensory characteristics to the food products such as flavor, texture and taste which ultimately determines consumer acceptability of new products.

Innophos Expertise

At Innophos, we leverage our knowledge of the interactions between phosphates and commonly used plant-based proteins (e.g., soy, pea, fava, lentil, etc.) to optimize the functional properties of the protein and help manufacturers develop plant-based meat substitutes that offer similar flavor and textural characteristics to their meat counterparts (Table 1).

Phosphates modulate protein functionalities in many ways. Phosphates can change pH and ionic strength or can chelate metals in the protein solutions indirectly affecting the properties of the protein. Phosphates also exhibit polyelectrolyte behavior, binding proteins and water through electrostatic interactions. The phosphate-protein interaction is influenced by pH changes, the addition of cations, and the phosphate chain length, which determines the degree of ionization.

Table 1. Phosphate salts influence on functional properties of selected plant-based protein

			FUNCTIONAL PROPERTIES		
COMMON NAME	PLANT DERIVED FROM	% PROTEIN	FAC[a]	EC/ES[b]	GELATION[c]
Soy Protein Isolate	*Glycine max*	90%	PS2, PS4, PS6 (increase)	PS2, PS6, PS9	PS4 (harder); PS2 (softer)
Pea Protein Isolate	*Pisum sativum*	83%	PS7 (increase)	PS6, PS8	PS4 (harder); PS6 (softer)
Lentil Protein	*Lens culinaris*	51%	PS3 (decrease)	PS8	PS3 (harder); PS7 (softer)

[a]Fat absorption Capacity (FAC) – Measures the ability of a protein to absorb oil.

[b]Emulsifying Capacity (EC) and Emulsifying Stability (ES) – Measures the ability of the protein to emulsify and stabilize the newly created emulsion.

[c]Gelation – Measures the firmness and the ability of the protein to form viscoelastic gels.

The table shows some examples of how to modify the functionalities of a few plant-based proteins with the help of phosphates.

- Fat absorption influences flavor retention and texture. When developing a soy-based meat substitute, adding phosphate salts (e.g. PS2, PS4, PS6) will increase fat absorption resulting in a more savory product. When working with lentil protein, the addition of PS3 may decrease the amount of fat being absorbed.
- Emulsification and gelation affect texture. When making a soy protein-based product, adding PS2 will result in better emulsification properties and a softer product.

Pea Protein Isolate Formulations

Pea protein continues to gain share versus other proteins in meat substitute formulations due to its unique processing characteristics.[5,6] This protein has a well-balanced amino acid profile, a low glycemic index, and contains two globular protein fractions: globulins and albumins. Pea proteins have intrinsic functional properties such as the ability to bind fat and generate a firm texture after thermal processing that also make them appealing. However, pea proteins have limitations when it comes to their capacity to bind water and form gels. Leveraging our knowledge of phosphates, we undertook several studies to determine how we could increase juiciness and modify texture of meat substitutes.

Increasing Juiciness

Juiciness is related to the WHC and is key to a successful meat substitute product.[7] The WHC is at its lowest, at the isoelectric point where the net charge of the protein in the solution is zero. Changing the pH, which changes the charges on the ionizable groups and alters the conformation of the protein as well as changing the ionic strength of the solution, can influence the WHC.

Table 2 shows that the addition of a phosphate (PS6) improved the WHC of the pea protein isolate at room temperature and at elevated temperature. The WHC measures the ability of a protein to prevent water from being released from its three-dimensional structure and plays a significant role in imparting textural attributes (e.g. juiciness), which is important in processed meats.

Table 2. WHC properties of Pea Protein Isolate at two temperatures in the presence of phosphate[a].

PROTEIN	WHC @ ROOM TEMPERATURE	WHC @ 82°C
Pea Isolate 1- Control	2.7	2.7
Pea Isolate 1 + PS6	2.9	3.0

[a]Note: Experimental conditions - 5 g protein, water to create a paste (water added at ambient temperature or at 82°C to mimic hydration at elevated temperature), with and without 1% phosphate salt. Samples are centrifuged @ 3,000 rpm for 12 minutes. Centrifuged tube is weighed after supernatant is removed. WHC = $(W_2-W_1)/W_0$ where W_0 is weight of dry sample (g), W_1 is weight of tube plus dry sample (g) and W_2 weight of the tube plus sediment (g).

Modifying Texture

Gelation contributes to the formation of viscoelastic gels and is important to impart the desired textural attributes to a product. Heat-induced gel formation is a process in which a protein unfolds, rearranges, associates and aggregates to form a three-dimensional network. Gelation is affected by the solubility of the protein, which is at its weakest near the isoelectric point. The addition of phosphates changes the pH and ionic strength of the solution which impacts the gelation of the proteins. Another factor impacting gelation is temperature.

Figure 1 shows gel strength of the pea protein isolate when we added different phosphates. The addition of PS4 enabled the formation of a firm gel-like structure, while the addition of PS6 resulted in a more homogeneous dispersion of the pea protein.

Figure 1. Pea Protein Isolate with different gel strength[b].

[b]Note: Experimental conditions - 10% protein (w/w) + with or without 1% PS (w/w); Heated with shear at 90°C for 25 min. Cooled at refrigeration temperatures (37°F) for 24 hrs before measuring firmness with a texture analyzer.

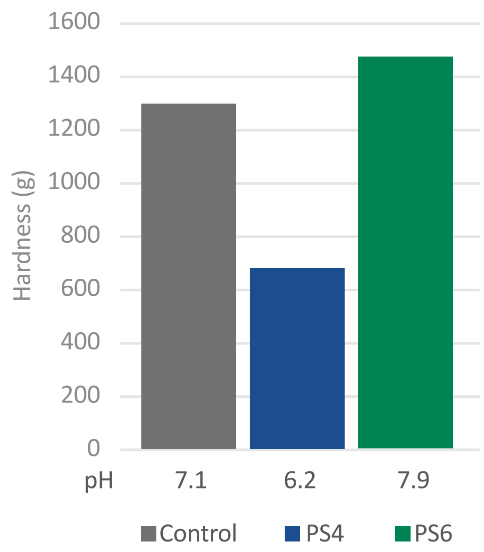
Finished Product: Plant-Based Hot Dog

Products such as sausages, hot dogs, and bologna are examples of meat emulsion products. They consist of finely chopped meat used to form a stable mixture that binds water and traps fat. The stability of these emulsions depends on the water holding capacity and emulsification properties of the proteins in the matrix. Using pea protein isolates, we prepared a plant-based hot dog (Example 1) and evaluated the effect of different phosphates on the textural properties of the emulsified meat analogue with a texture analyzer (Graph 1).

Example 1. Emulsified sausage formulation

SAUSAGE COMPONENTS	%
Pea Protein Isolate (85%)	23.0
Vegetable Oil	4.0
Water	68.4
Starch	2.0
Phosphate Salt	1.0
Salt	0.5
Carrageenan	0.3
Guar Gum	0.1
Xanthan Gum	0.1
Nutritional Yeast	0.6
TOTAL	**100.0**

Graph 1. Hardness and pH of Plant-Based Hot Dog



The study shows:

- The addition of PS4 resulted in a softer hot dog with a lower pH
- The addition of PS6 resulted in a harder hot dog and higher pH

Finished Product: Plant-Based Chicken Patty

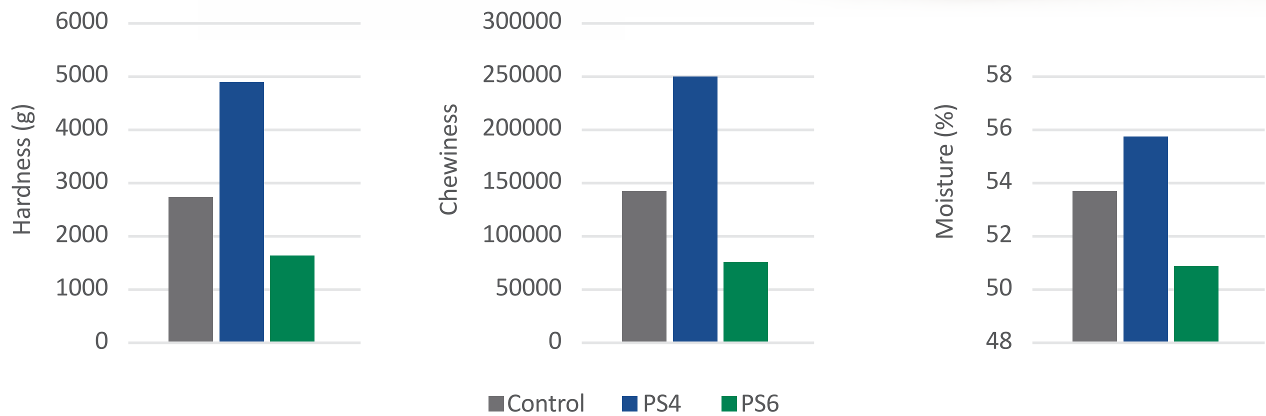
Ground meat products such as burgers, patties and nuggets have a characteristic bite, chewiness, hardness, and juiciness. They consist mainly of proteins and fats. Plant-based substitutes are typically formulated with textured vegetable protein (TVP) to mimic the fibrous and firmness textural properties of these types of meat products; however, TVP does not provide the same organoleptic properties as meat.

In this example, we formulated a meatless chicken patty using a textured pea protein containing the ingredients described in Example 2. The texturized pea protein was hydrated in water at room temperature for 60 minutes. After hydration, the texturized protein was chopped using a food processor to achieve 2 – 3 mm particles. The mixture was molded into 40 g patties and refrigerated for at least 12 hours. The patties were baked at 375°C for 30 minutes. We evaluated the patties after 3 hours at room temperature (Graph 2).

Example 2. Meatless chicken patties formulation

PATTIES COMPONENTS	%
Nutralys® T70S	15.2
Methylcellulose	1.4
Coconut Oil 76°	5.7
Pea Fiber I50M	1.0
Potato Starch	0.8
Phosphate Salt	1.0
Salt	0.5
Gellan Gum LT100	0.3
Onion/Garlic Powder	0.1
Acacia Gum	0.1
Water	73.8
TOTAL	**100.0%**

Graph 1. Hardness, Chewiness and Moisture Content of Plant-Based Chicken Patty



The study shows:

- The addition of PS4 resulted in patties that were firmer, had better binding and chewiness, higher moisture, and lower pH (pH=5.8) than the control (pH=7.1)
- The addition of PS6 had the opposite effect in these types of products (pH=8.1)

Summary

Consumer adoption of plant-based meat substitutes depends on delivering a good sensory experience. Phosphates play a critical role in helping formulators develop appealing plant-based products by improving water holding capacity, fat absorption, emulsification, and gelling properties of the proteins. Phosphates influence protein functionalities by changing their physicochemical properties as they interact with functional groups and charges.

By understanding plant-based protein functionalities and modulating with phosphates, manufacturers can develop meat substitutes with better textural profiles for consumers seeking heathy and sustainable food products. Innophos' phosphate expertise and our extensive application knowledge are unique resources for manufacturers seeking to develop premium meat substitute products.

Reach out to our technology team to optimize your plant-based protein products.

www.innophos.com

1. Markets and Markets, Plant-Based Meat Market by Source (Soy, Wheat, Pea), Product (Burger Patties, Strips and Nuggets, Sausages, Meatballs) and Type (Beef, Chicken, Pork, Fish), Process, and Region - Global Forecast to 2025.

2. International Food Information Council (IFIC) Survey: Consumption Trends, Preferred Names, and Perceptions of Plant-Based Meat Alternatives, November 3, 2021.

3. Sha,L. & Xiong, Y (2020). Plant protein-based alternatives of reconstructed meat: Science, Technology and Challenges. Trends in Food Science and Technology, 51-61.

4. Kyriakopoulou,K., Keppler, J. & van der Goot, A. (2021). Functionality of Ingredients and Additives in Plant-Based Meat Analogues. Foods, 1-29.

5. Shand, P., Ya, H., Pietrasik, Z & Wanasundra, P. (2007). Physicochemical and Textural Properties of Heat-Induced Pea Protein Isolate Gels. Food Chem., 1119-1130.

6 Zhu, H., Tang, H., Cheng, Y.Q., Li, Z. & Tong, L. (2021). Potential of Preparing Meat Analogue by Functional Dry and Wet Pea (Pisum sativum) Protein Isolate. Food Science and Technology, 111702.

7 Cornet, S., Snel, S., Lesschen, J. & van der Goot, A. (2021). Enhancing the Water Holding Capacity of Model Meat Analogues Through Marinade Composition. Journal of Food Engineering. 1-9.